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COMPARE THE EXPERIMENTAL PERFORMANCE OF V-SHAPED BLACK COTTON AND JUTE CLOTH FLOATING WICKS SOLAR STILLS IN INDIAN CLIMATIC CONDITION

ABHAY AGRAWAL[1] & R. S. RANA[2]

[1]*Assistant Professor, Department of Mechanical Engineering, Rewa Engineering College, Rewa, MP, India*

[2]*Department of Mechanical Engineering, Maulana Azad National Institute of Technology, Bhopal, MP, India*

ABSTRACT

The single basin single slope conventional solar still gives less amount of distillate output. Therefore, some modifications are proposed for conventional solar still in order to improve the performance and increase the amount of distillate output. In the present work, three similar conventional solar still units were fabricated. An experimental study was conducted in central India at Rewa (M.P.) (Latitude: 24°33' 20.81" N, Longitude: 81°18' 49.1" E) in all three units of solar still with same outdoor environmental conditions. Modification was done in two units out of three units of solar still, in which first unit of solar still was modified by using V-shaped black cotton cloth floating wicks and second unit was modified by using V-shaped black jute cloth floating wicks. The effect of solar radiation, ambient temperature, cotton cloth floating wick temperature, jute cloth floating wick temperature, glass cover temperature, basin water temperature, hourly distillate output and daily distillate output of modified (cotton and jute cloth floating wick) and conventional solar stills were studied. Higher distillate output was obtained in modified solar still as compared to conventional solar still due to higher surface area of V-shaped profile and low thermal inertia of floating wick. Comparison of experimental performance of V-shaped cotton and jute cloth floating wicks modified solar stills were also carried out. It is observed that the V-shaped cotton cloth floating wicks still produced higher distillate output in comparison to the other two stills. The total daily distillate outputs of V-shaped cotton cloth floating wicks still, V-shaped jute cloth floating wicks still and conventional still were 8.272 Kg/m^2/day, 7.880 Kg/m^2/day and 4.700 Kg/m^2/day respectively.

KEYWORDS: Solar Still, Floating Wick, Jute Cloth, Cotton Cloth, Distillate Output & Nocturnal Output

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Original Article

INTRODUCTION

Our earth is different from other planets, because water is available here. Due to this availability of water, life on the earth has been possible. Two third of the earth is surrounded by water and one third is covered by land. Most of the water available on the earth is salty water (3000 PPM to 35,000 PPM) which is not suitable for human being. Demand of potable water is increasing day by day due to increase in population and rapid growth in industries. It can be satisfied only by the conversion of salty water into potable water with the help of solar distillation technology. Due to wide availability of solar radiation in most parts of India, the problem of drinking water can be overcome completely using solar distillation technique.

In the process of solar distillation, saline water is evaporated using solar energy, and converted into water vapor, which is collected as a potable water after condensation. solar still is a device through which solar

distillation process is conducted. It can be fabricated by locally available material. The solar still is a rectangular black painted box in which the saline water is filled. It is enclosed by the transparent cover. The heat of solar radiation evaporates the saline water which is then condensed through the transparent cover and finally collected as a distillate output (pure water).

The daily productivity of conventional solar still is much less. So numerous attempts have been made by many researchers to suggest various modified designs of a solar still for enhancing its efficiency by providing maximum evaporation surface area within the available space of the still. Dunkle [1] had given the empirical relations of convective and evaporative heat transfer coefficients of conventional basin type solar still. Trial and error method was used to calculate the glass cover temperature for given basin water temperature and ambient temperature using heat balance equations. Lof et al. [2] had analyzed the effect of different design parameters and climatic parameters on the performance of solar still. Cooper [3,4] developed a simulation method of analyzing complicated transient solar still processes and determined the maximum efficiency of horizontal solar still. Sodha et al. [5] presented the design, analysis and performance of a multiple wick solar still in which series of blackened jute cloth pieces of increasing length separated by thin black polythene sheets, resting on foam insulation supported by a net of nylon ribbon were used. Their upper edges were dipped in a saline water tank. On a typical cold sunny day in Delhi, the distillate output was 2.5 l/m^2/day, corresponding to an overall efficiency of 34 per cent. Karaghouli and Minasian [6] proposed a floating-wick type solar still. Itwas simply a conventional solar still provided with a blackened jute wick floated with a polystyrene. Results of this study showed that the floating-wick type solar still gives higher productivity than the common tilted-wick type and the conventional basin-type solar stills.

The maximum daily output of this proposed new still is 10.5 l/m^2. Sakthivel et al. [7] presented a new approach to improve the efficiency of a solar still by introducing a medium to provide large evaporation surface and utilize the latent heat of condensation. An experiment was conducted on a conventional single slope solar still and on a regenerative solar still with jute cloth which was kept vertically in the middle of basin saline water and also attached with the rear wall of the still in order to provide the large evaporation surface area. A mathematical model was also developed using Dunkle's model. Its performance was compared with the conventional still under the same climatic condition. It was found that there is 9% deviation from the experimental result. It was also found that cumulative still yield in the regenerative still with jute cloth increases approximately by 20% and efficiency increases by 8%. Murugavel and srithar [8] studied the performance of basin type double slope solar still with minimum mass of water and different wick materials like light cotton cloth, sponge sheet, coir mate and waste cotton pieces in the basin. It was found that, the still with light black cotton cloth is the most effective wick material. The still with rectangular aluminum fin covered with cotton cloth and arranged in length wise direction was more effective. Srivastava and Agrawal [9] conducted experimental and theoretical work and improved the performance of the conventional basin type solar still incorporating multiple low thermal inertia porous absorbers (blackened jute cloth) floated adjacent to each other on the basin water with the help of thermocol insulation.

It was found that on clear days the average gain of distillate output was 68%, whereas it was 35% on partially clear days. Matrawy at el. [10] presented thermal model and experimental study of a corrugated wick type solar still in which the productivity of a solar still was enhanced by the modification in the evaporative surface using black clothes in a corrugated shape that are immersed in water where the clothes absorbs water and get saturated by capillary effect. It was found that the productivity for the proposed wick type solar still increases by about 34% as compared to the simple basin

type solar still. Agrawal et al. [11] conducted an experimental and theoretical comparison of heat transfer coefficients and productivity of a single slope single basin solar still in Indian climatic condition for five different basin water depths (2 cm to 10 cm). It was found that the theoretical and experimental values of daily distillate output for lowest basin water depth (2 cm) are 5.37 kg/m2/d and 4.26 kg/m2/d respectively. For highest basin water depth (10 cm), corresponding values are 4.17 kg/m2/d and 3.24 kg/m2/d respectively. The results indicated that daily distillate output decreased with increase in basin water depth.

In this paper, modifications have been incorporated in the single basin single slope solar stills. The first unit of modified solar still consists of V-shaped black cotton cloth floating wicks and second unit consists of V-shaped black jute cloth floating wicks. Numbers of experiments have been conducted to analyze and compare the performance of modified solar stills and conventional solar still. The effect of operational parameters, such as solar radiation, ambient temperature, cotton and jute cloth floating wick temperature, basin water temperature, glass temperature and distillate output (day and nocturnal) of modified solar stills have also been presented. The main objective of this study is to enhance the productivity through modifications in conventional solar still.

Experimentation

Experimental work was conducted in outdoor environmental condition at Rewa Engineering college, Rewa, M.P., India (Latitude: 24°33' 20.81" N, Longitude: 81°18' 49.1" E). Three units of single slope, single basin solar still are placed along the east-west direction with south-facing inclined glass cover surface. To enhance the quantity of distillate output, two units of conventional solar still are modified by introducing the V-shaped black cotton cloth and black jute cloth floating wicks on the surface of basin water. The schematic diagram and experimental setup photograph of modified solar still are shown in Figure 1 and Figure 2 respectively. Each conventional unit of solar still is fabricated by galvanized iron sheet (0.001 m thick). Firstly, the galvanized sheet box of rectangular size of the dimension 0.80 m x 0.65 m x 0.20 m is prepared. The inside surface of basin box (all sides and bottom) is painted black to absorb more and more solar radiation coming inside the solar still. This metallic basin box is placed in the plywood box whose two sides are rectangular and other two sides are trapezoidal. Polystyrene sheet of 0.005 m thick is used as an insulating material between metallic basin box and plywood box in order to reduce the heat transfer losses. Simple window glass (0.004 m thick) is used as a condensing cover of solar still. It is fitted inclined on the top edges of the plywood frame and making an angle of 24° from the horizontal. Silicone rubber and glass putty are used to fill the gaps between glass cover and plywood box edges in order to minimize the leakage of vapors. Distillate output comes out from the solar still through the aluminum channel, which is fitted on the lower edge of the plywood frame.

A graduated bottle is used to collect the distillate output. All three conventional units of solar still are tested for their synchronization. The results of performance of all three solar stills show a good synchronization. After this, two units of solar still are selected for incorporating the modification. In first modified unit, V-shaped black cotton cloth floating wicks are floated on the basin water surface of solar still. It is made by three thermocol pieces and form a triangular bar. Two adjacent triangular surfaces of triangular bar are wrapped by extended length of black cotton cloth and third surface is floated on the basin water. The extended cotton cloth is dipped into the basin water and due to capillary action, the surface of cotton cloth remains wet and maintains the low thermal inertia and high rate of evaporation. Four pieces of V-shaped black cotton cloth floating wick are prepared and floated side by side in order to completely cover the basin water surface. Similarly in second modified unit of solar still, black jute cloth is used instead of cotton cloth for preparing the V-shaped

black jute cloth floating wick. The V-shaped profile of cotton and jute cloth floating wick is shown in Figure 3. All three solar stills are filled by ground water (TDS value of 1043 mg/ml) of Rewa region at same level of basin water depth (2 cm). The temperature at various points (glass cover, cotton cloth floating wick, jute cloth floating wick, basin water and basin liner) of all three solar stills is measured by calibrated Ni-Cr thermocouple wires which are connected with dual channel digital thermometers. Solar radiation, ambient temperature and wind speed data are collected from the SRRA (Solar radiation resource assessment) station at Rewa Engineering College, Rewa, Madhya Pradesh, India. The experimentations were conducted in all three modified and conventional solar stills during the month of April 2017 (summer season). Each experiment was carried out for five to six days. Hourly readings of solar radiation, ambient air temperature, wind speed, and temperatures at different points of all three solar stills were recorded from 8:00 A.M. to 8:00 P.M. and then at 8:00 A.M. of the next morning. In this way, 24 hours of experimental observations were recorded including nocturnal performance.

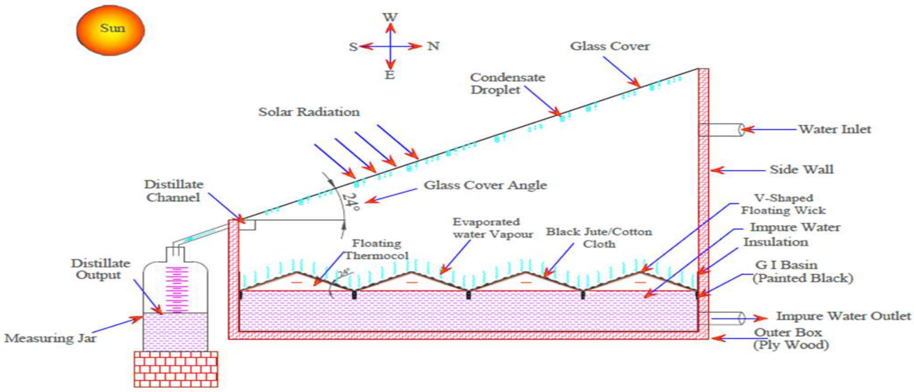

Figure 1: Schematic Diagram of V-shaped Cotton and Jute Cloth Floating Wicks Modified Solar Still

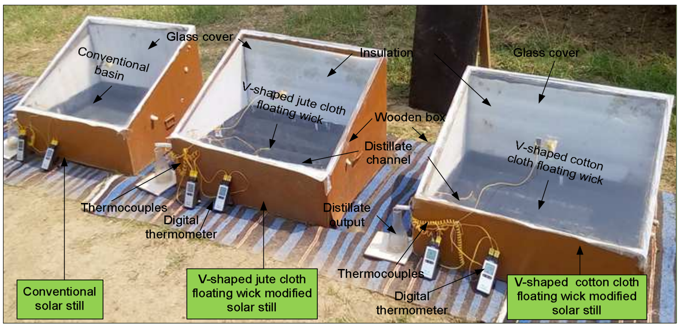

Figure 2: Photograph of Experimental Setup of Modified and Conventional Solar Stills

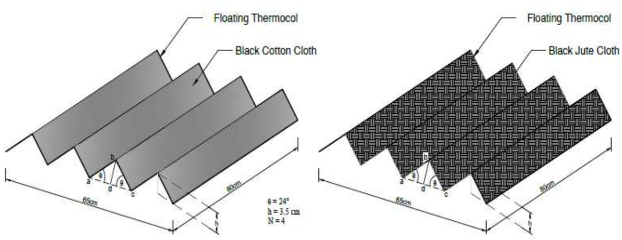

Figure 3: Schematic Diagram of V-shaped Profile of Cotton and Jute Cloth Floating Wicks

RESULTS AND DISCUSSIONS

The experimentations were conducted in three different units of single slope single basin solar still under the same climatic condition of Rewa in the month of April, 2017. First unit was simple conventional type and second and third units were modified form of the solar still. Second unit contains blackened jute cloth V-shaped floating wick pieces and third unit contains blackened cotton cloth V-shaped floating wick pieces in order to enhance the evaporating surface area of solar still. The results and discussion of proposed work has been presented in following sections.

As shown in Figure 4, it is noticed that the solar radiation intensity was initially low during sunrise after that it gradually increases and attains maximum intensity at mid noon, then gradually decreases till the sunset. For the solar radiation intensity, maximum value is 917 W/m^2 at 12:00 hrs whereas the ambient air temperature reaches its maximum value at 15:00 hrs. The reason behind the time lag between the peak values of solar radiation intensity and ambient air temperature is due to high thermal inertia of atmospheric air. The solar radiation intensity and ambient air temperature in clear day of summer season were in range of 0 – 917 W/m^2 and 29.5 − 40.93 °C respectively with duration of about 12 hours of a day.

Figure 5 clearly depicts the hourly variation of black cotton cloth and jute cloth floating wick surface temperatures and basin water temperatures of modified and conventional stills. It can be observed from the figure that, from the morning hours, floating wick surface temperature of both modified solar stills are rapidly increased due to increase in solar radiation and reaching its maximum values at around 13:00 h and then decreases gradually till evening, whereas in conventional still, the maximum basin water temperature is reached at around 14:00 h. The experimental values of maximum temperature of cotton cloth and jute cloth floating wick surfaces of modified stills were 73 °C and 71 °C respectively around 13:00 h. For conventional still, the maximum value of basin water temperature was 67.9 °C at around 14:00 h. An important observation is that the cotton cloth floating wick surface attained the highest temperature among all water surfaces of solar stills. This is because of the porosity (%), capillary rise (mm/h), heat transfer coefficient (W/m^2 °C) and low thermal inertia of cotton cloth wick [a] is greater than the Jute cloth, so that cotton cloth was quickly heated and increases the temperature of wick surface.

Figure 6 shows the hourly variation of experimental values of glass cover temperatures for the V-shaped cotton and jute cloth floating wick modified stills and conventional still. It can be seen that the glass cover temperature of cotton wick still is higher than the other two stills. The properties of cotton cloth and extended evaporating surface area using V-shaped profile of cotton wick are the reasons behind the higher glass temperature of cotton floating wick still during morning hours to evening hours. Maximum temperature of glass cover was reached at around 13:00 h. This time duration is more or less similar for both modified and conventional stills. Maximum measured values for modified (cotton floating wick and jute floating wick) and conventional stills were 68 °C, 66 °C and 59.3 °C respectively.

Figure 7 shows hourly variation of distillate output of V-shaped cotton cloth floating wick still, V-shaped jute cloth floating wick still and conventional still. It can be observed that the V-shaped cotton cloth floating wick still gives the higher distillate output in comparison to the other two stills. This may be due to higher heat transfer coefficient and low thermal capacity of the cotton cloth wick. Therefore, it is quickly heated from the starting of the day (7:00 a.m.) to the sunset (7:00 p.m.) and holds a thin film of water due to capillary action in the fibers of cotton cloth that converts into distillate output with higher rate of evaporation as compared to the V-shaped jute cloth still. It is indicated from the figure

that the maximum distillate output for cotton wick still and jute wick still were obtained as 1.22 Kg/m^2/h, 1.16 Kg/m^2/h respectively at the time of 13:00 h. and the maximum distillate output for conventional still was 0.73 Kg/m^2/h at around 14:00 h.

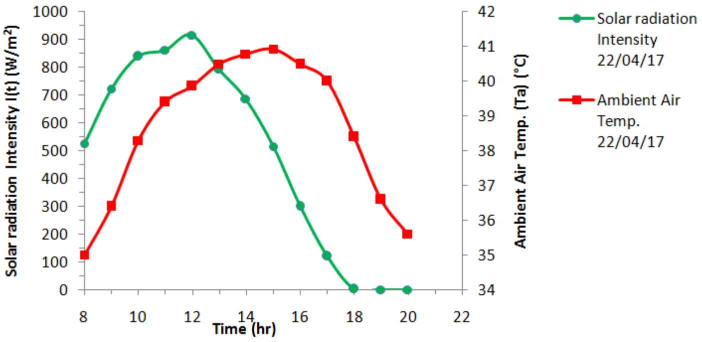

Figure 4: Hourly Variation of Solar Radiation Intensity and Ambient Air Temperature on a Typical Summer Day

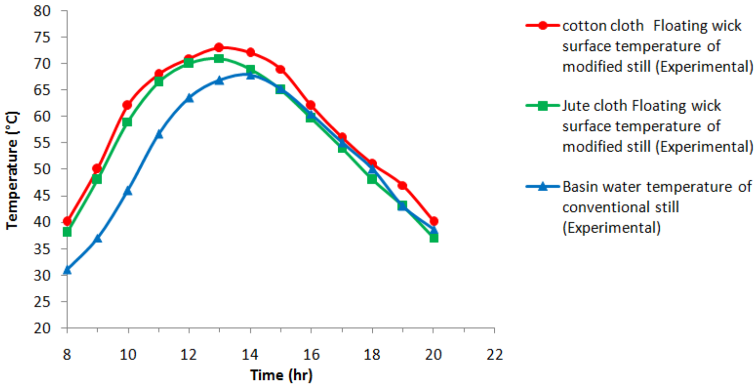

Figure 5: Hourly Variation of Cotton and Jute Cloth Floating Wick Surface Temperatures and Basin Water Surface Temperatures of Modified and Conventional Solar Stills

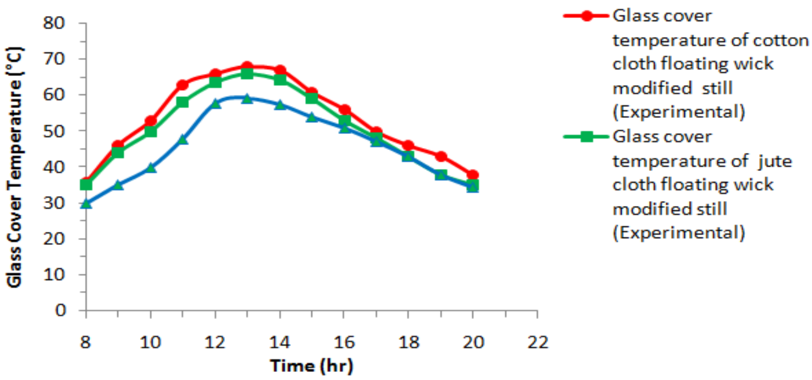

Figure 6: Comparison of Glass Covers Temperatures of Modified and Conventional Solar Stills

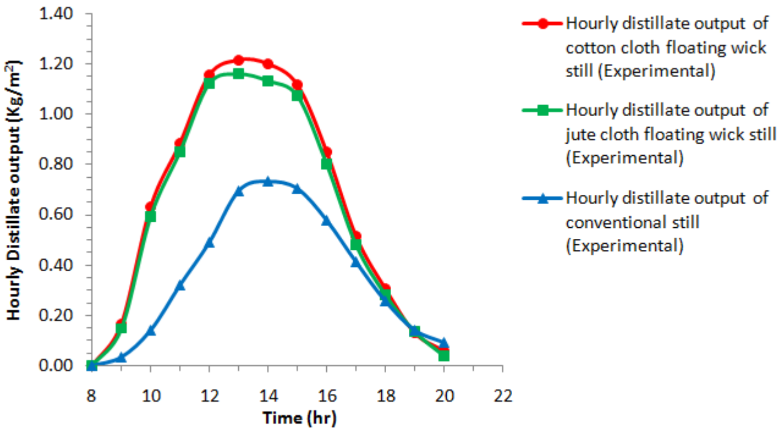

Figure 7: Hourly Variation of Experimental Values of Distillate Output of Modified and Conventional Stills

Figure 8 shows the comparison of hourly variation of cumulative distillate output for V-shaped cotton cloth floating wick still, V-shaped jute cloth floating wick still and conventional still for 24 hours (8 a.m. to 8 a.m. the next morning) on 22/04/2017. It is clearly found from the figure that the daily distillate output of cotton wick and jute wick stills are increased by approximately 75.95% and 67.65% respectively over the conventional still. Figure indicates the distillate output of day time, night time and one complete day of all three solar stills. The values of distillate output of cotton wick still, jute wick still and conventional still for day time (8:00 a.m. to 7:00 p.m.) were 8.18 Kg/m^2, 7.78 Kg/m^2 and 4.52 Kg/m^2 respectively and for night (8:00 p.m. to 7:00 a.m.) were 0.092 Kg/m^2, 0.100 Kg/m^2 and 0.180 Kg/m^2 respectively. It can be observed that the amount of distillate output obtained during night (nocturnal distillate output) is much lesser than the distillate output during day time in modified solar stills than conventional still. The reason for this fact is that the maximum solar radiation is absorbed by wet surface of floating wick and very small amount of heat is transfer to the basin water. Therefore, less amount of nocturnal output is collected in modified solar stills as compared to conventional still. The total daily distillate output of above solar stills are 8.272 Kg/m^2/day, 7.880 Kg/m^2/day and 4.700 Kg/m^2/day respectively.

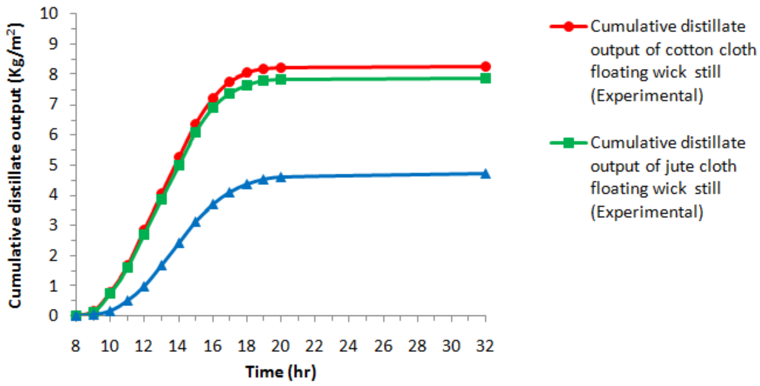

Figure 8: Comparison of Experimental Values of Cumulative Distillate Output for Modified and Conventional Stills

CONCLUSIONS

Based on the results of experiments conducted on V-shaped black cotton cloth floating wicks still, V-shaped black jute cloth floating wick still and conventional still under the climatic condition of Rewa, India, the following conclusions can be drawn.

- It is observed that the floating wick surfaces of modified solar stills are quickly heated as compared to conventional still due to low thermal inertia of floating wick as compared to basin water. The experimental values of the maximum temperature of cotton and jute cloth floating wick surface of modified stills are 73 °C and 71°C respectively around 13:00 h. For conventional still, the maximum value of basin water temperature is 67.9 °C at around 14:00 h.
- The glass cover temperature of V-shaped cotton floating wicks still is higher than that of V-shaped jute floating wicks still and conventional still both. The maximum values of temperature of modified and conventional stills are 68 °C, 66 °C and 59.3 °C respectively.
- It can be seen that the difference between cotton and jute cloth floating wick surface temperature and glass cover temperature is higher than that for conventional solar still.
- The V-shaped cotton floating wicks still gives higher distillate output as compared to V-shaped jute floating wicks still. This is due to higher heat transfer coefficient and low thermal capacity of cotton cloth as compared to jute cloth.
- The distillate output of modified solar stills during day time is much higher than that of conventional still due to an increase of the evaporating area by introducing V-shaped profile of floating wick and use of low thermal inertia materials (cotton and jute) as evaporating surface. The maximum values of distillate output for V-shaped cotton floating wicks still and V-shaped jute floating wicks still are obtained at 1.22 Kg/m^2/h and 1.16 Kg/m^2/h respectively at the time of 1:00 p.m. and the maximum distillate output for conventional still is obtained as 0.73 Kg/m^2/h at around 2:00 p.m.
- The hourly variation of cumulative distillate output for V-shaped cotton floating wicks still is higher than that of V-shaped jute floating wicks still and conventional still. The percentage increase of daily distillate output of V-shaped cotton and jute floating wicks stills is 75.95% and 67.65% respectively as compared to conventional still. The experimental values of daily distillate output of these three solar stills are 8.272 Kg/m^2/day, 7.88 Kg/m^2/day and 4.70 Kg/m^2/day respectively.
- The values of nocturnal output in modified solar stills are much less as compared to conventional still. The values of nocturnal output for V-shaped cotton floating wicks still, V-shaped jute floating wicks still and conventional still are 0.092 Kg/m^2, 0.100 Kg/m^2 and 0.180 Kg/m^2 respectively.
- The solar distillation technology is very useful in countries like India, where a lot of rural and remote areas are available with sufficiently high solar radiation input. It is a feasible solution to provide potable water to villagers at low cost.

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